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Author's address

Denis Lavoie (delavoie@nrcan.gc.ca)
Geological Survey of Canada - Quebec
490 rue de la Couronne
Québec, Quebec G1K 9A9

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Hydrothermal dolomitization in the Lower Silurian La Vieille Formation in northeastern New Brunswick: field evidence and implication for hydrocarbon exploration[1]

Denis Lavoie

Lavoie, D., 2005: Hydrothermal dolomitization in the Lower Silurian La Vieille Formation in northeastern New Brunswick: field evidence and implication for hydrocarbon exploration; Geological Survey of Canada, Current Research 2005-D1, 10 p.

Abstract: Research oriented towards the understanding of the hydrocarbon potential of the Late Ordovician to Middle Devonian Gaspé Belt in Northern New Brunswick is being carried out under the Targeted Geoscience Initiative. Preliminary results have allowed the author to recognize large areas with thermal maturation favourable for the preservation of hydrocarbons, and to identify stratigraphic intervals with fair to good hydrocarbon source-rock potential. This contribution presents field observations that indicate that the Lower Silurian La Vieille Formation has undergone some early hydrothermal alteration that led to dolomitization, brecciation, leaching, and the development of porous intervals into which hydrocarbons have migrated. Hydrothermal dolomites are host to world-class hydrocarbon reservoirs in North America. The process has been recently documented in the Gaspésie Peninsula and is now recognized in northern New Brunswick.

Résumé : Des recherches axées sur la compréhension du potentiel en hydrocarbures de la ceinture de Gaspé (Ordovicien tardif à Dévonien moyen), qui est située dans le nord du Nouveau-Brunswick, sont en cours dans le cadre de l'Initiative géoscientifique ciblée. Les résultats préliminaires ont permis de reconnaître de grandes régions présentant des conditions de maturation thermique favorables à la préservation d'hydrocarbures, et d'identifier des intervalles stratigraphiques ayant un potentiel moyen à bon comme roches mères pour les hydrocarbures. Cette contribution présente des observations de terrain suggérant que la Formation de La Vieille (Silurien inférieur) a subi une altération hydrothermale précoce qui y a engendré de la dolomitisation, de la bréchification, de la dissolution, et le développement d'intervalles poreux dans lesquels ont migré des hydrocarbures. Certaines dolomies hydrothermales en Amérique du Nord renferment des réservoirs d'hydrocarbures de classe mondiale. Le processus en cause a récemment été documenté dans la péninsule de Gaspésie et est maintenant reconnu dans le nord du Nouveau-Brunswick.

[1]Contribution to the Targeted Geoscience Initiative 2003–2005

INTRODUCTION

Hydrothermal dolostones host major hydrocarbon accumulations in the United States and Canada, and include the world-class Ordovician Albion-Scipio (Michigan) and Devonian Ladyfern (British Columbia–Alberta) fields. Moreover, a large number of hydrocarbon fields in southern Ontario and adjacent New York State are hosted by hydrothermal dolostones in Ordovician rocks. A significant percentage of the latter fields occur in Taconian foreland basin limestones and are capped by impermeable fine-grained clastic rocks (Hurley and Budros, 1990). The limestones are cut by extensional or strike-slip faults, which channelized overpressured and high-temperature fluids that brecciated, leached, and dolomitized the limestone host (Hurley and Budros, 1990). One of the critical elements for increased reservoir potential of these dolostones is the earliness of hydrothermal alteration of the limestone — early postdepositional alteration results in a better reservoir, as the still-porous rocks have a better potential for fluid flow (Davies, 1997; Smith, 2004; Lavoie and Morin, 2004).

Hydrothermal dolostone is an exploration target in the Paleozoic successions of eastern Canada (Cooper et al., 2001). Exploration strategies in western Newfoundland and adjacent Anticosti Island focus on the potential of hydrothermal dolostone in Ordovician passive-margin and foreland-basin carbonate rocks (Cooper et al., 2001; Lavoie and Chi, 2003; Lavoie, 2004). Hydrothermal dolomitization and associated brecciation, corrosion, and leaching are also documented in the Lower Silurian Sayabec Formation in the Gaspésie Peninsula (Lavoie and Chi, 2001; Lavoie and Morin, 2004).

This paper presents field observations from the Lower Silurian La Vieille Formation in northeastern New Brunswick. In the southern Gaspésie Peninsula and northern New Brunswick, the La Vieille Formation is a coeval, facies-correlative unit of the Sayabec Formation of northern Gaspésie (Lavoie et al., 1992; Lavoie and Chi, 2001; Lavoie and Morin, 2004). Crosscutting field relationships between various tectono-sedimentary and diagenetic elements are presented to support early hydrothermal alteration of the La Vieille Formation.

This research is part Appalachian Energy project of the Targeted Geoscience Initiative (2003–2005). In northern New Brunswick, various activities aim to define the hydrocarbon potential of the Acadian Gaspé Belt (Wilson et al., 2004). The preliminary research results show that in segments of northern New Brunswick, thermal maturation is favourable for preservation of hydrocarbons and that Upper Ordovician hydrocarbon source rocks are likely present (Bertrand and Malo, in press).

METHODS

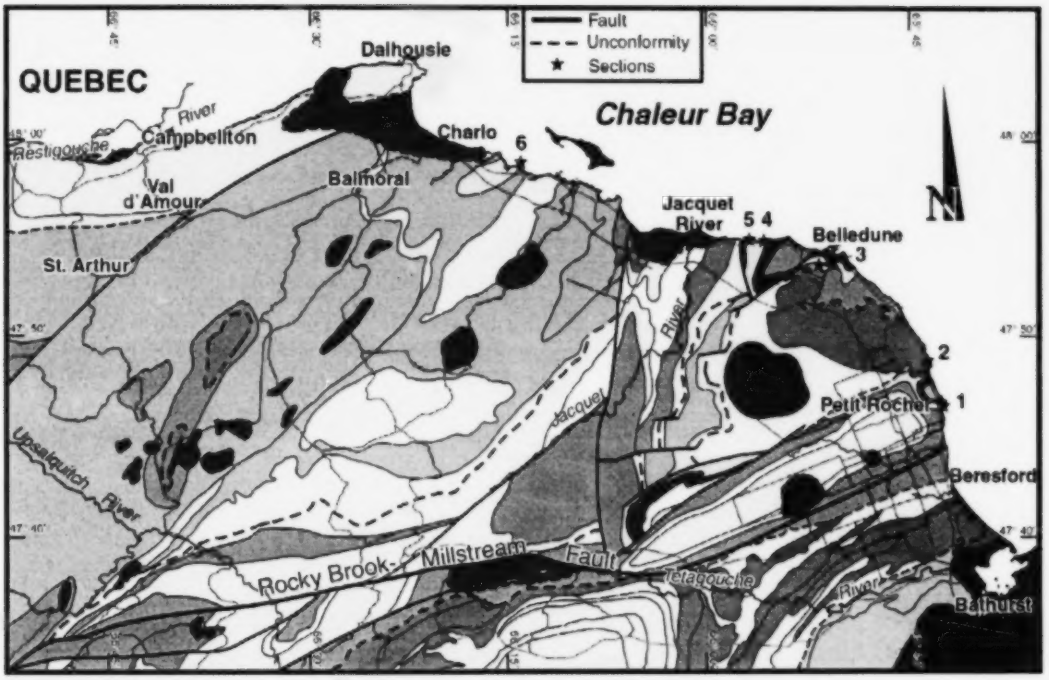
During the summer of 2004, 6 stratigraphic sections (Fig. 1) of the Lower Silurian La Vieille Formation were carefully examined for facies architecture and evidence of hydrothermal alteration of the limestone facies. Forty-five samples were collected for future petrographic and carbon and oxygen stable isotopes ratios analyses. Moreover, four sections of the Upper Silurian Laplante Formation were also described and sampled for future contributions.

GEOLOGICAL SETTING

The Gaspé Belt extends from eastern Gaspésie Peninsula in Québec, southwest through northwestern New Brunswick to northeastern Maine (Fig. 1). The Gaspé Belt encompasses Upper Ordovician to Middle Devonian rocks that outcrop in three major structural divisions, the Connecticut Valley–Gaspé synclinorium, Aroostook–Percé anticlinorium, and Chaleurs Bay synclinorium (Bourque et al., 2001) (Fig. 1). The Gaspé Belt in northern New Brunswick is underlain by the latter two entities. The Gaspé Belt comprises three successions separated by Late Silurian (Salinic) and Early Devonian unconformities (Wilson et al., 2004). The lower succession records a post-Taconian basin infilling event. This first event is expressed in the Upper Ordovician to Lower Silurian siliciclastic turbidites of the Grog Brook Group, overlain by calcareous turbidites of the Matapédia Group, the regressive phase culminates in slope and shelf deposits of the lower part of the Chaleurs Group and is represented by Upsalquitch and Limestone Point formations that are laterally equivalent to the subtidal to peritidal La Vieille Formation (Lee and Noble, 1977; Wilson et al., 2004) (Fig. 2). Above the Salinic unconformity, the upper Chaleurs Group and the Dalhousie Group record a transgressive-regressive cycle. Locally, at the base of the middle package, Ludlovian(?) coarse- to medium-grained clastic rocks of the Simpson Field Formation are overlain by mixed outer shelf clastic and carbonate rocks of the Pridolian Laplante Formation, in which local reefal facies are recognized (Noble, 1985). In northern New Brunswick, Wilson et al. (2004) recognized the Pridolian reefal facies of the West Point Formation and overlying Pridolian to Lochkovian sedimentary rocks of the Indian Point Formation. The Chaleurs Group is conformably overlain by Lochkovian to early Emsian subaerial volcanic and subordinate siliciclastic rocks of the Dalhousie Group. The Dalhousie Group is in northern New Brunswick, unconformably overlain by alluvial-lacustrine deposits of the late Emsian Campbellton Formation (Wilson et al., 2004). This paper primarily addresses the facies developed at the end of the first regressive event in the Gaspé Belt in northern New Brunswick, that is the La Vieille Formation.

The lower succession (Upper Ordovician to end Lower Silurian) was affected by the Salinic Orogeny (van Staal and de Roo, 1995). This orogenic pulse is manifested in synsedimentary extensional block faulting, within-plate volcanism, uplift, and deep erosion of basement and Upper Ordovician to Lower Silurian strata (Wilson et al., 2004), and in significant tectonic instability recorded by the sediments shed onto deep marine slopes.

The siliciclastic-dominated Paleozoic succession of the Gaspé Belt (Bourque et al., 2001; Wilson et al., 2004) contains few shallow-water carbonate units, besides reef and



LEGEND

EARLY CARBONIFEROUS
- Bonaventure Formation

DEVONIAN
- Felsic to intermediate intrusive rocks

EARLY DEVONIAN
- Campbellton Formation

Dalhousie and Tobique groups
- Mitchell Settlement, Sunnyside and Val d'Amour formations
- Archibald Settlement Formation
- Jacquet River, Big Hole Brook and Wapske formations
- Greys Gulch Formation

EARLY to LATE SILURIAN

Chaleurs Group
- Indian Point and Free Grant formations
- Laplante Formation
- Benjamin Formation, includes New Mills Formation
- Mafic volcanic rocks (Bryant Point Formation; includes South Charlo Formation)
- Simpsons Field Formation
- **La Vieille Formation**
- Weir Formation
- Upsalquitch and Clemville formations

LATE ORDOVICIAN to EARLY SILURIAN
- Matapédia Group
- Grog Brook Group

EARLY to LATE ORDOVICIAN
- Sedimentary rocks of the Tetagouche, California Lake and Fournier groups
- Mafic volcanic rocks of the California Lake, Tetagouche, Fournier and Balmoral groups
- Felsic volcanic rocks of the California Lake and Tetagouche groups

LATE CAMBRIAN to EARLY ORDOVICIAN
- Sedimentary rocks of the Miramichi Group

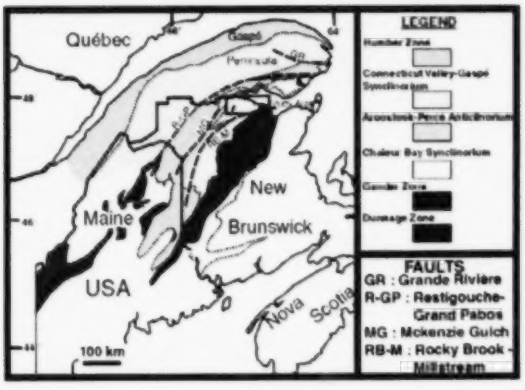
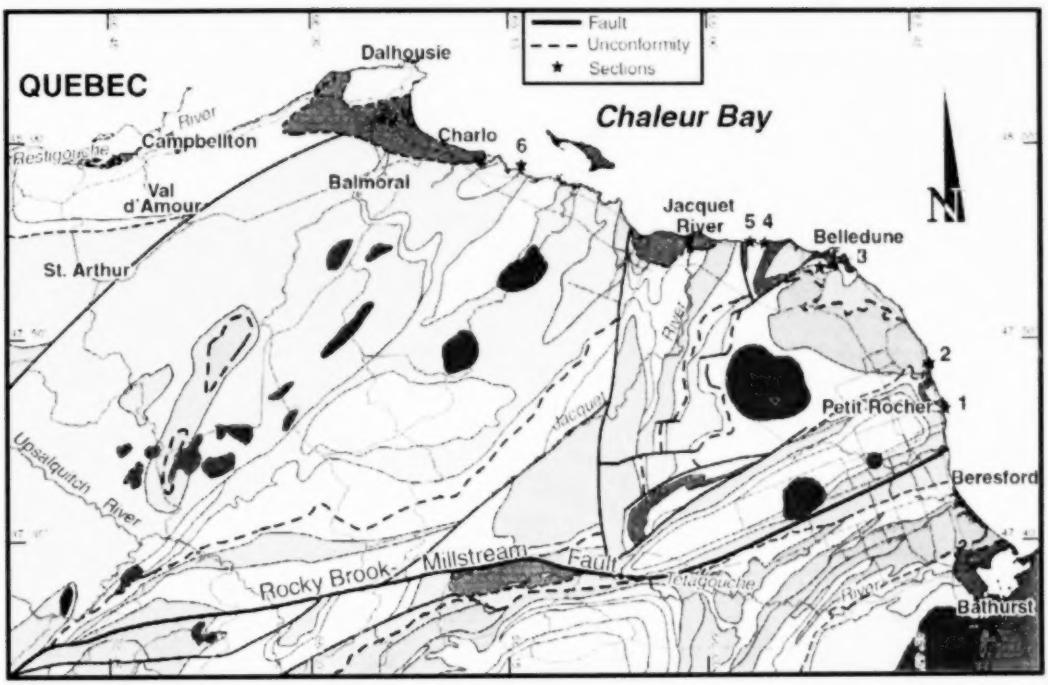


Figure 1: *Simplified geological map of northern New Brunswick (New Brunswick Department of Natural Resources, 2000) with the location of the six studied stratigraphic sections of the La Vieille Formation. Refer to the inset map for the overall tectonostratigraphic setting of the study area.*



SCALE

0 5 10 15 20 25

km

LEGEND

EARLY CARBONIFEROUS

DEVONIAN

EARLY DEVONIAN

Dalhousie and Tobique groups

EARLY to LATE SILURIAN

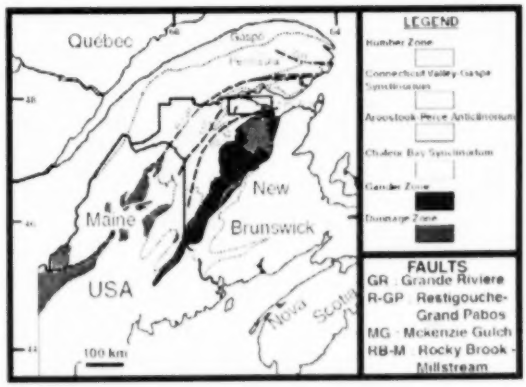
Chaleurs Group

La Vieille Formation

LATE ORDOVICIAN to EARLY SILURIAN

EARLY to LATE ORDOVICIAN

LATE CAMBRIAN to EARLY ORDOVICIAN



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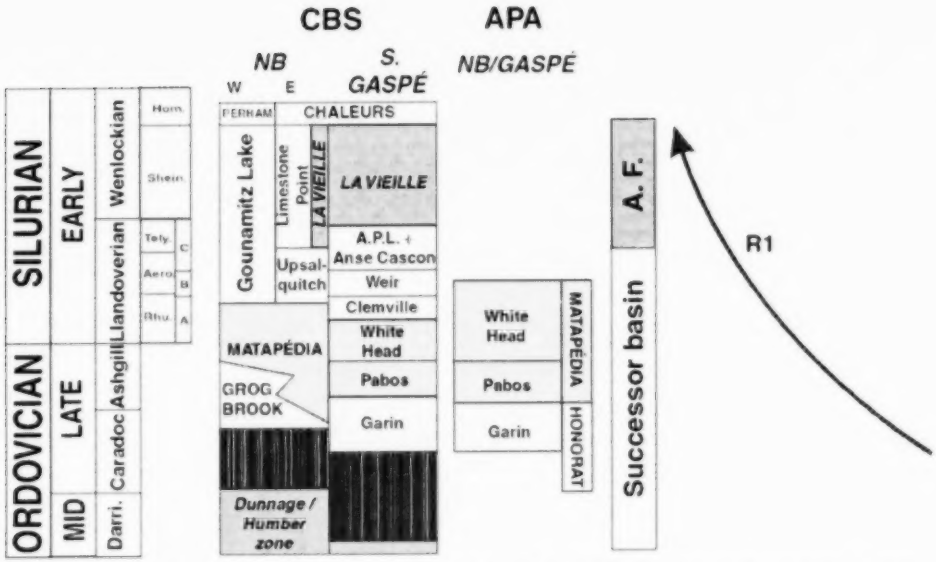


Figure 2: *Stratigraphic chart for the Late Ordovician to Early Silurian time in the eastern (E) and western (W) sectors of northern New Brunswick (NB) and southern Gaspésie. The Lower Silurian La Vieille Formation is an uppermost Llandoverian to upper Wenlockian unit. In northern New Brunswick, the La Vieille only outcrops in the eastern sector; to the west and northwest, the La Vieille is spatially replaced by the coeval, deeper marine units of the Limestone Point and Gounamitz Lake formations. In the Gaspésie Peninsula and New Brunswick, the La Vieille was deposited near the end of the first major regressive event (R1) that followed the Taconian Orogeny. Good hydrocarbon source rocks are now known in the underlying Upper Ordovician Grog Brook Group/Garin Formation and in the Middle Ordovician Dunnage Zone black shales (Popelogan Formation; Bertrand and Malo, in press). A.F.: Acadian foreland basin, APA: Aroostook-Percé anticlinorium, A.P.L.: Anse-à-Pierre-Loiselle Formation, CBS: Chaleurs Bay synclinorium. Ordovician substage: Darri: Darriwilian. Silurian substages: Aero: Aeronian, Hom: Homerian, Rhu: Rhudantian, Shein: Sheinwoodian, Tely: Telychian.*

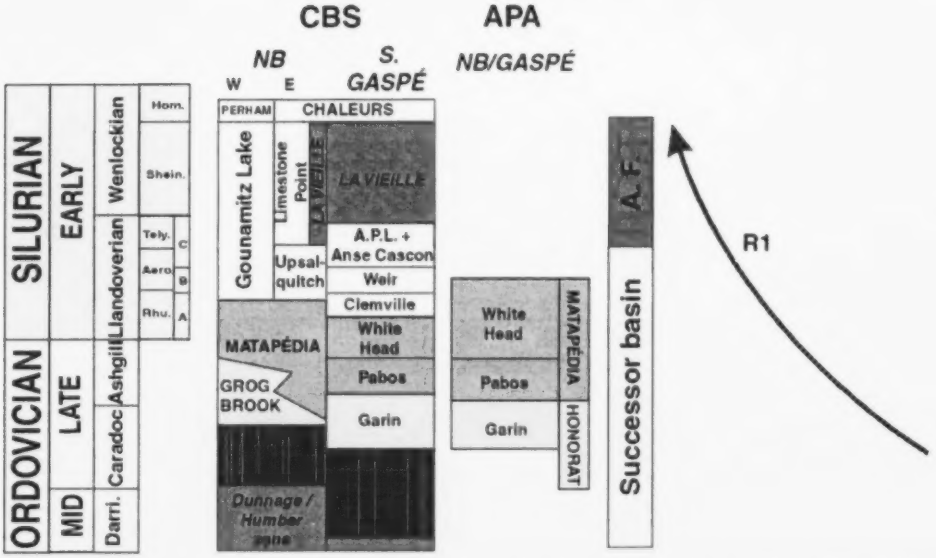
carbonate complexes that developed during the late Llandoverian-Wenlockian and the late Ludlovian-Lochkovian intervals. The Lower Silurian La Vieille Formation represents the first shallow-water limestones in the Paleozoic succession of the northern segment of the Appalachian Orogen (Bourque et al., 1986; Lavoie et al., 1992; Wilson et al., 2004). In northern New Brunswick, the outer shelf–peritidal La Vieille Formation outcrops in the eastern sector of the Chaleurs Bay synclinorium; to the west, the unit is laterally equivalent to the slope–outer shelf facies of the Limestone Point and Upsalquitch formations (Wilson et al., 2004) (Fig. 2).

LA VIEILLE FORMATION

The type area of the La Vieille Formation is in the Port Daniel–Gascon area in southern Gaspésie Peninsula (Schuchert and Dart, 1926). These authors also recognized that unit in northeastern New Brunswick. All these localities are within the Chaleurs Bay synclinorium (Fig. 1). Stratigraphic descriptions for the New Brunswick occurrences were provided by Noble (1976) and Lee and Noble (1977).

In the Gaspésie Peninsula and northern New Brunswick, the La Vieille Formation typically consists of three units defined as informal members by Lavoie et al. (1992) in Gaspésie. These consist of 1) a lower nodular, locally highly fossiliferous limestone member of outer shelf origin (Fig. 3a), 2) a middle well bedded wackestone to packstone calcarenite of subtidal origin with local (southern Gaspésie) algal-metazoan bioherm/biostrome belt that rims a wide spectrum of algal and cryptobacterial facies (laminites, stromatolites, thrombolites, and oncolites) of peritidal origin (Fig. 3b and c), and 3) an upper nodular, poorly fossiliferous limestone member that records a return to outer-shelf conditions.

In northern New Brunswick, the typical three-fold division of the La Vieille Formation is recognized in sections adjacent to the Elmtree Inlier (Dunnage Zone; Fig. 1, sections 2, 3, 4 and 5), whereas at some distance away from this inlier, the middle unit is seemingly absent (Fig. 1, sections 1 and 6) and the formation is represented only by the nodular limestone



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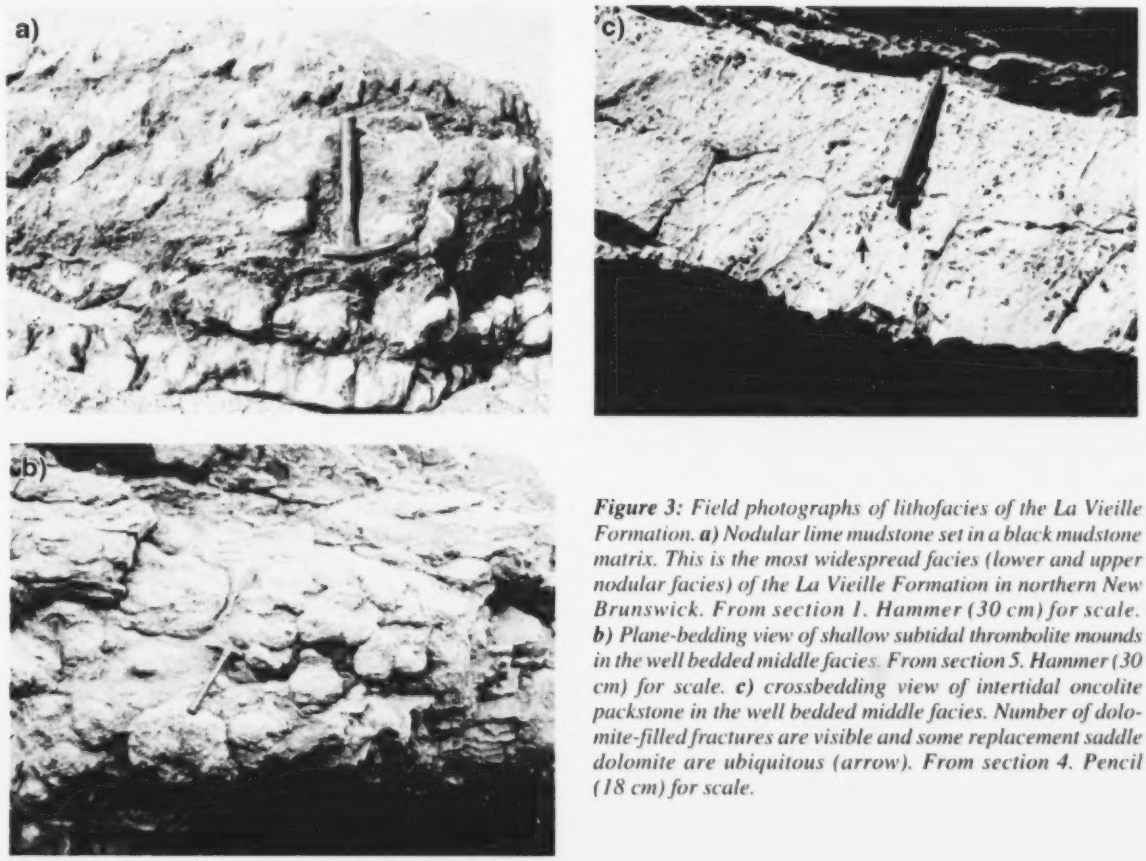

Figure 3: *Field photographs of lithofacies of the La Vieille Formation.* ***a)*** *Nodular lime mudstone set in a black mudstone matrix. This is the most widespread facies (lower and upper nodular facies) of the La Vieille Formation in northern New Brunswick. From section 1. Hammer (30 cm) for scale.* ***b)*** *Plane-bedding view of shallow subtidal thrombolite mounds in the well bedded middle facies. From section 5. Hammer (30 cm) for scale.* ***c)*** *crossbedding view of intertidal oncolite packstone in the well bedded middle facies. Number of dolomite-filled fractures are visible and some replacement saddle dolomite are ubiquitous (arrow). From section 4. Pencil (18 cm) for scale.*

facies. Further to the west, the La Vieille is replaced by the coeval deep-marine facies of the Upsalquitch Formation (Wilson et al., 2004).

Biostratigraphic data for the La Vieille Formation in northern New Brunswick is abundant, the age of the unit is fairly well constrained to be Llandoverian C6 (e.g. late Telychian)–early to middle Wenlockian based on brachiopods (Noble, 1976; Lee and Noble, 1977) or late Telychian from chitinozoans (Asselin, unpub. rept., 2001).

EARLY HYDROTHERMAL ALTERATION OF THE LA VIEILLE FORMATION

High temperature dolomites (HTD) are a significant play for exploration companies looking for large hydrocarbon reservoirs in North America and, in particular, in eastern Canada (Eaton, 2004; Lavoie, 2004). The evidence for hydrothermal alteration (leaching, brecciation, dolomitization; Davies, 1997; Smith, 2004) of a precursor limestone can be classified into 1) field evidence (early fractures, brecciation, dissolution, collapse, dolomite cements/replacement, early extensional–transtensional–strike slip faults), 2) petrographic and geochemical evidence (presence of saddle dolomite, very light oxygen stable-isotope signature of the dolomite, high homogenization temperatures of highly saline fluid inclusions in dolomite) and 3) indirect seismic expression (sag or collapse of platform interval, loss of seismic marker because of intense brecciation, presence of a nearby fault network). This contribution presents field observations that corroborate hydrothermal alteration of the La Vieille Formation in northern New Brunswick.

Early fractures

In all known cases of efficient porosity/permeability systems associated with hydrothermal dolomitization, an irregular network of early fractures is often ubiquitous (Smith, 2004).

Two major fracture systems are found in the nodular and well bedded facies. The first one consists of an highly irregular, anastomosed system (Fig. 4a), without any preferred orientation, that is significantly better developed in the well bedded middle unit of the La Vieille Formation. The width of these fractured zones varies from 2 mm up to 15 cm, and the nature of the infills is discussed later in this paper. The irregular early fracture set was observed at localities 2, 3 , 4 and 5 (Fig. 1). This first fracture set is commonly less irregular when cutting through the nodular facies. The second system is very regular and apparently relates to regional folding.

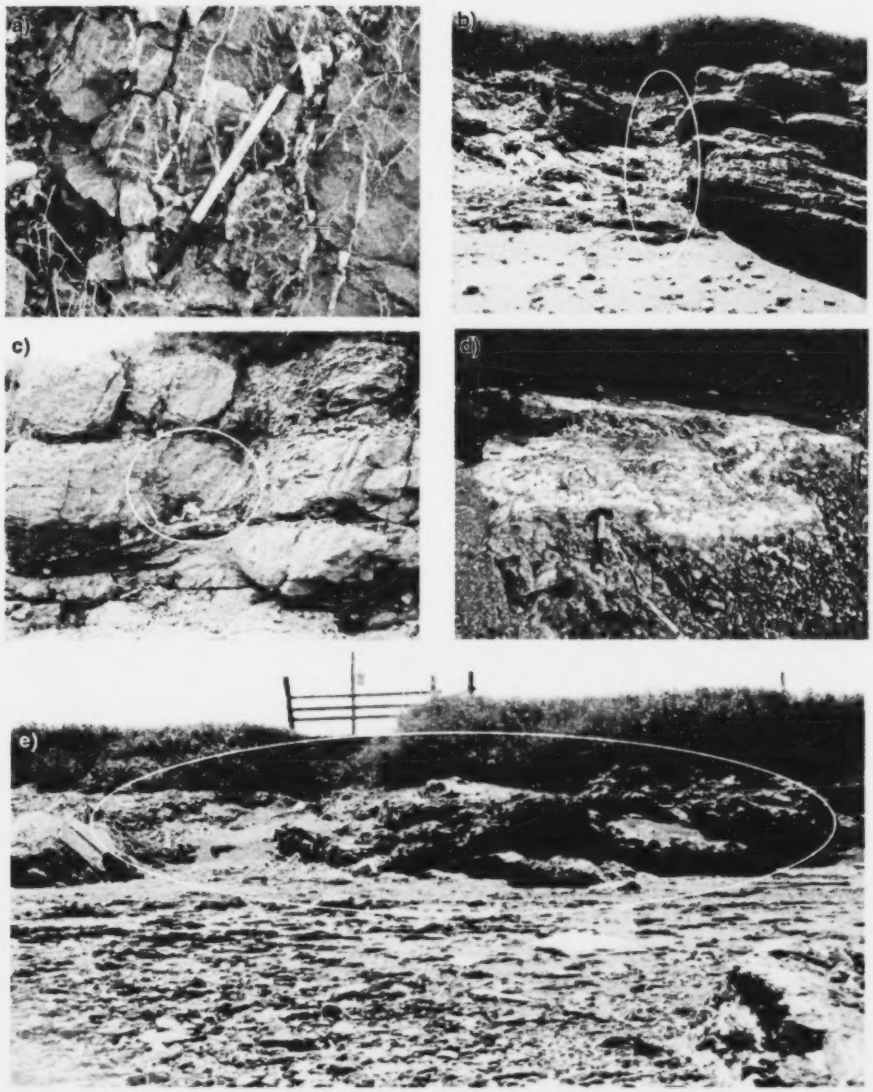

Figure 4. *Field photographs of tectono-diagenetic elements in the La Vieille Formation.* ***a)*** *Highly irregular and dense network of early fractures filled by buff-coloured dolomite cements cutting through a bioclastic wackestone of the La Vieille Formation. These early fractures are cut by regular fractures filled by white calcite cements. From section 3. Pen (18 cm) for scale.* ***b)*** *Highly brecciated interval (circled) associated with a minor fault that cut through the middle well bedded unit of the La Vieille Formation. From section 4. Exposed length of the brecciated zone is 3.2 m and is 80 cm wide.* ***c)*** *Dissolution cavity (circled) with very irregular walls; the floor and roof of the cavity are lined by an early phase of dolomite cements with calcite cements as late precipitate, see Figure 5C for a close-up. Void found in the middle well bedded unit. From section 5. Hammer (30 cm) for scale.* ***d)*** *Large dissolution cavity filled by alternating dolomite (buff-coloured zones) and calcite (white zones) cements. Large parts of the cavity infilling is a breccia made up of fragments of the dolomite and calcite cements. Cavity in the lower nodular mud facies. Photo courtesy of Ivan Dimitrov (University of New Brunswick). From section 1. Hammer (40 cm) for scale.* ***e).*** *Large-scale collapse of the well bedded middle unit (circled area) of the La Vieille Formation. The beds are highly distorted, brecciated, and discordant to the regularly bedded nodular facies that underlies (left end of the photograph) the middle unit. Width of the collapse zone (circled area) is 12 m. From section 4.*

Brecciation associated with early fractures

In hydrothermal dolomite plays, significant brecciation of the host limestone/dolostone is invariably associated with the early fracture system (Smith, 2004).

Two major brecciated zones have been found associated with the early fracture system in the well bedded facies of the La Vieille Formation at locality 4 (Fig. 1). The brecciated intervals occur in intensely fractured areas (Fig. 4b). The breccia is clast supported and the fragments are highly irregular and angular in shape which indicate little remobilization. In between the clasts, a fine limestone matrix is commonly present; at a few places, small isopachous crusts of calcite cement are noted.

Dissolution features associated with early fractures

A common element of the HTD system is the presence of locally huge dissolution voids/caverns that connect the early fracture system (Smith, 2004). These voids are sometimes associated with subaerial exposure and meteoric water karstification. In many cases, the geochemical characteristics of the infilling carbonates (stable-isotope ratios, fluid-inclusion microthermometry) unequivocally rule out a meteoric origin (Lavoie and Chi, 2001).

Two large dissolution voids are noted in the La Vieille Formation at localities 1 and 5 (Fig. 1). The first one occurs in the well bedded middle unit of the formation (Fig. 4c); the cavity is 1.6 m in diameter and the early fracture system merges with it. Early dolomite and later calcite cements (*see* below) in the fracture coat the wall of the cavity, suggesting a temporal and physical relationship between the two type of voids. The second cavity (I. Dimitrov, pers. comm. 2004) occurs in the black nodular facies of the La Vieille Formation. It is 3 m in diameter with alternating cement growth zones and bands of cement clasts (Fig. 4d).

Large scale collapse of sections

The large-scale dissolution, brecciation, and to some extent dolomitization of the precursor limestone result in significant collapse of segments of the altered limestone platform. This is critical in the identification of HTD in seismic profiles (Smith, 2004) and can be observed in some well exposed field sections.

A significant collapse of the entire well bedded middle unit of the La Vieille Formation can be observed at the coastal section of locality 4 (Fig. 1). The internal stratigraphy of the 25 m thick middle unit is irregular and discordant to the lower and upper nodular limestone facies of the unit (Fig. 4e).

Fracture-filling cements

Diagenetic studies of cements found in HTD systems have resulted in the documentation of a complex suite of carbonate-sulphate-silica cements, not to mention various base-metal sulphides and bitumen that are present in fractures and dissolution voids (Chi and Lavoie, 2001; Lavoie and Morin, 2004; Smith, 2004). It is now well established that dolomite precedes calcite, and that sulphate (barite) and silica are common late phases. Base-metal sulphides (sphalerite and less commonly galena) and bitumen are either common or absent (Chi and Lavoie, 2001). Saddle dolomite (Radke and Mathis, 1980) is possibly the best known characteristic of the hydrothermal dolomite play (Lavoie and Chi, 2001; Chi and Lavoie, 2001; Lavoie and Morin, 2004; Smith, 2004).

The early irregular fracture set is filled by up to three cement phases with the complete succession only seen in the larger fractures (Fig. 5a and b). The first cement phase consists of millimetre- to centimetre-sized, buff-coloured dolomite crystals and is sometimes slightly calcareous (dedolomitization?). In most fractures, this first cement is covered by large, centimetre-sized crystals of white calcite that commonly fill remaining void space. In large cavities, such as the one at locality 5, dolomite crystals form fan-shaped crusts over the irregular wall of the void (Fig. 5c). Future petrographic work should document the presence or absence of saddle dolomite in these dolomite cements. In some fractures, in particular those at localities 4 and 5 (Fig. 1), large amounts of black material (most likely bitumen, possibly along with sphalerite) are seen between dolomite and calcite cements (Fig. 5b).

Pervasive dolomitization

Pervasive dolomitization of the precursor limestone facies is invariably associated with the hydrothermal dolomite play. However, the intensity and lateral extension of the dolomitization is highly variable and is controlled by a complex fluid temperature–ion concentration/solubility system as well as by the presence of an efficient plumbing system to carry hydrothermal solutions rich in Mg^{+2} (Smith, 2004).

Pervasive dolomitization of the La Vieille Formation is uncommon and was observed only at locality 4 (Fig. 1). At that locality, an irregular-shaped zone consisting of fine-grained dolomite was observed (Fig. 5d). The zone is centred on an open fracture and the dolomitization front extends 2.2 m from the main fracture.

Synsedimentary tectonic instability

Faults are the main conduits for hydrothermal fluids to migrate upwards and reach chemically reactive limestones (Davies, 1997). Extensional and/or strike-slip faults are documented as major plumbing system for all HTD reservoirs. On the other hand, reverse and/or thrust faults are poor candidates for fluid migration as they are more commonly seals than conduits (Smith, 2004; Lavoie and Morin, 2004). Early movements (shortly after sedimentation) along these faults have been proposed as a prerequisite for intense hydrothermal dolomitization (Smith, 2004).

In northern Gaspésie Peninsula, seismic data and detailed kinematic studies have documented significant late Early to Late Silurian extensional movement along major regional faults interpreted to be related to the Salinic Disturbance (Bourque et al., 2001; Kirkwood et al., 2002). These faults

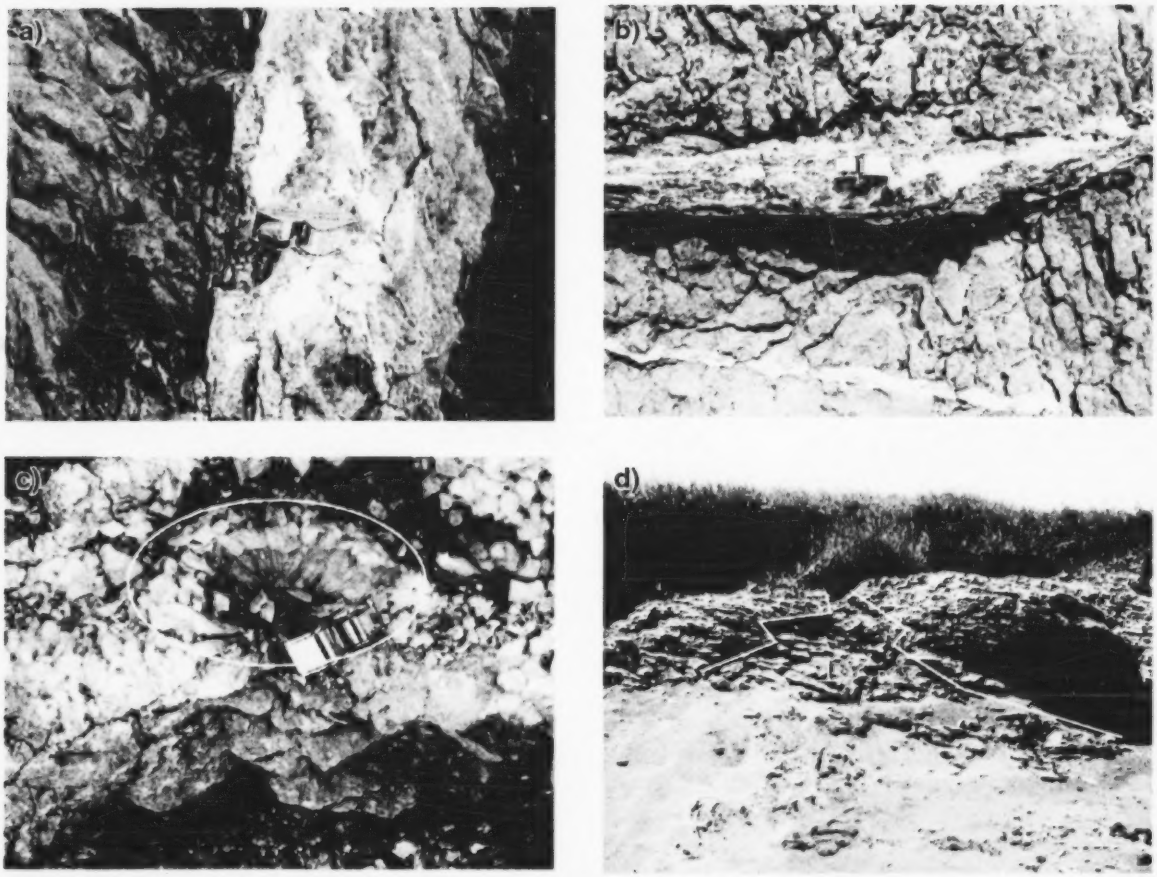

Figure 5. *Field photographs of diagenetic elements in the La Vieille Formation.* ***a)*** *Fracture filled by early large crystals of dolomite (saddle-type?) cement (buff coloured) with large white calcite crystals filling remaining void space. From section 5. Lens (6 cm) for scale.* ***b)*** *Fracture filled by an early phase of buff-coloured dolomite cements, this is followed, inward, by black material consisting of bitumen and minute sphalerite crystals, the centre of the fracture is filled by white calcite cement. From section 5. Lens (6 cm) for scale.* ***c)*** *Close up of Figure 4C, fan-shaped crust (circled) of dolomite cements coating a protuberance on the floor of the cavity, the tip of the crystals consists of white calcite cement. From section 5. Lens (6 cm) for scale.* ***d)*** *Pervasive dolomitization of the middle well bedded unit of the La Vieille Formation. The dolomitization front (outlined buff-coloured zone) extends away from a fracture. From section 4. Hammer (30 cm) for scale.* ***e)*** *Two well rounded dolomicrite clasts (arrows) embedded in a clast-supported debris-flow unit at the top of the La Vieille Formation. The dolomicrite is identical to the dolomitized facies observed on Figure 5D. From section 2. Pencil (18 cm) for scale.*

were most probably originally listric and south to southeast dipping and have induced block tilting along their hanging wall. Although seismic data is unavailable in northern New Brunswick, a kinematic study of key major faults is in progress (Dimitrov, 2003). The recent organic matter maturation study of northern New Brunswick (Bertrand and Malo, in press) suggests the probable presence of such synsedimentary south-facing tilted blocks formed in Early Silurian time. Moreover, the presence of a nodular limestone facies restricted succession along many of the studied sections of the La Vieille Formation indicates local synsedimentary collapse of part of the La Vieille carbonate ramp. A similar synsedimentary collapse has been proposed for Lower Silurian carbonate facies of the adjacent Gaspésie Peninsula (Lavoie et al., 1992; Lavoie and Morin, 2004).

Field evidence of such synsedimentary tectonic instability is visible at locality 2 (Fig. 1), which is characterized by a well exposed succession of the deep marine (below wave bases) Limestone Point Formation. The section shows multiple evidence for significant instability on the depositional slope including slump folds, dismembered beds, and synsedimentary breccia. At the southern end of the section, facies of the La Vieille Formation are well exposed. The top of the uppermost beds of the La Vieille Formation is marked by a 1.5 m thick debris-flow unit. In that chaotic debris-flow interval, clasts of dolomitized La Vieille facies are noted (Fig. 5e). The dolomite clasts are similar to the fracture-associated dolomitized zone described above; this indicates dolomitization is early and that faults were active in the Gaspé Belt basin in Lower Silurian time.

SUMMARY OF RECENT AND ONGOING RESEARCH ON THE HYDROCARBON POTENTIAL OF NORTHERN NEW BRUNSWICK

The Gaspé Belt in Gaspésie Peninsula has been the subject of intermittent hydrocarbon exploration since the 1850s (Lavoie and Bourque, 2001). Over 80 natural hydrocarbon seeps are reported with limited, but economic, gas production in Lower Devonian limestones in eastern Gaspésie (Lavoie et al., 2001). Since 2001, all prospective lands in the Gaspésie Peninsula are under exploration licenses with exploration drilling and seismic exploration programs underway.

The extension of the Gaspé Belt in northern New Brunswick has received little consideration by the hydrocarbon industry, mostly because of the lack of modern hydrocarbon system (source rocks, maturation, potential reservoirs, traps and seals) and seismic data. New mapping of the northernmost area of the province carried out under the eastern Canada NATMAP project (1999–2004), as well as thematic research on biostratigraphy and regional organic matter maturation have generated new frameworks and data that clearly indicate that this area could be hydrocarbon prospect (Wilson, 2003; Bertrand et al., 2004; Wilson et al., 2004).

These encouraging results led to the definition of targeted hydrocarbon-system studies of northern New Brunswick under the Appalachian Energy TGI-2 project (2003–2005). These activities include 1) extensive sampling for detailed organic maturation and identification of potential hydrocarbon source rocks, 2) study of the diagenetic evolution of Lower (La Vieille Formation) and Upper (Laplante Formation) Silurian carbonate rocks for their reservoir potential, and 3) detailed kinematic studies of major faults. The organic matter and source-rock studies are now completed (Bertrand and Malo, in press), maturation maps indicate that the northeast corner of the province has very favourable maturation for preservation of liquid and gas hydrocarbons. Maturation contours suggest the presence of south to southeast-dipping blocks bounded by extensional faults that were possibly active during the Silurian. The Rock Eval results indicate that Middle Ordovician black shales of the Popelogan Formation (Dunnage Zone), Upper Ordovician black shales in the Grog Brook Group (Ritchie Brook Member), and some coal-rich intervals in the Dalhousie Group are potentially fair to good hydrocarbon source rocks (Bertrand and Malo, in press); moreover, some preliminary data from the black nodular facies of the La Vieille Formation (Fig. 1, locality 1) suggest some potential (Bertrand and Malo, in press). In conclusion, 1) maturation is highly variable but highly favourable for significant areas, and 2) a number of regionally extensive stratigraphic units have fair to good hydrocarbon source-rock potential.

This article proposes that the Lower Silurian La Vieille Formation has undergone some hydrothermal alteration of its original limestone facies and that the hydrothermal dolomite play concept can be explored for in northern New Brunswick. Field observations clearly indicate that hydrocarbons (now bitumen) migrated in the early fracture system that cut through the facies. Future petrographic and geochemical research on the La Vieille facies will provide more detailed information on the hydrothermal system that affected the unit.

CONCLUSION

Comprehensive studies that target the understanding of the hydrocarbon potential of the Gaspé Belt in northern New Brunswick were initiated during the Eastern Canada Appalachian Forelands and Platform NATMAP project and expanded under the Appalachian Energy TGI-2 project.

The presence of significant areas with favourable conditions for preservation of both liquid and gaseous hydrocarbons, as well as the first documentation of a number of units with fair to good hydrocarbon source rock potential (Bertrand and Malo, in press) are the first elements in the evaluation of the potential of the belt. This preliminary contribution on the diagenetic evolution of Silurian carbonate rocks provides critical information pertinent to the hydrocarbon reservoir potential of these rocks.

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